

Claims

- [c1] 1. An exhaust aftertreatment system for a reciprocating internal combustion engine having at least one cylinder and a catalytic converter disposed in an exhaust duct of the engine which receives an exhaust gas stream from the engine, comprising a trap disposed in the exhaust duct located upstream of the catalytic converter, said trap is comprised of a porous ceramic or metallic material having a predetermined average pore size, said trap substantially fills the cross-section of the exhaust duct, a volume of said trap is less than 10% of a swept volume of the engine's cylinders coupled to said trap, wherein exhaust gases undergo multiple, random turns in traveling from an upstream side to a downstream side of said trap.
- [c2] 2. The exhaust aftertreatment system of claim 1, said average pore size is greater than about 80 micrometers.
- [c3] 3. The exhaust aftertreatment system of claim 1, said trap is capable of collecting more than 90% of particles greater than 50 micrometers in diameter.
- [c4] 4. The exhaust aftertreatment system of claim 1, said trap allows more than 50% of particles less than 1 micrometer in diameter to pass through.
- [c5] 5. The exhaust aftertreatment system of claim 1, said porous material is foam.
- [c6] 6. The exhaust aftertreatment system of claim 1, a pressure drop across said phosphorus trap is less than one kilopascal.
- [c7] 7. The exhaust aftertreatment system of claim 1 wherein said trap is located within 15 centimeters from an upstream end of the catalytic converter.
- [c8] 8. The exhaust aftertreatment system of claim 1, said porous material has a porosity greater than 90%.
- [c9] 9. The exhaust aftertreatment system of claim 10, wherein said trap is treated with a washcoat capable of catalyzing oxidation reactions of carbon monoxide and hydrocarbons in said exhaust gases.
- [c10] 10. An exhaust aftertreatment system for a spark-ignition, reciprocating

internal combustion engine having a catalytic converter disposed in an exhaust duct of the engine, comprising a trap disposed in the exhaust duct located upstream of the catalytic converter, said trap is comprised of a porous material substantially filling the cross-section of the exhaust duct, said porous material is comprised of a ceramic or metallic foam and has an average pore size greater than about 80 micrometers, said porous material has randomly oriented passageways forcing exhaust gases passing through said porous material to undergo multiple turns.

[c11] 11. The exhaust aftertreatment system of claim 10, further comprising an exhaust gas component sensor disposed in said exhaust duct, said exhaust gas component sensor is located downstream of said trap to protect said sensor.

[c12] 12. The exhaust aftertreatment system of claim 10, the engine has one or more pistons reciprocating within one or more cylinders, said porous material has a mass, in grams, which is less than a displacement, in cubic centimeters, of the cylinders coupled to said phosphorus trap divided by 25.

[c13] 13. The exhaust aftertreatment system of claim 10, wherein said trap is treated with a washcoat capable of catalyzing oxidation reactions of carbon monoxide and hydrocarbons in said exhaust gases.

[c14] 14. An exhaust aftertreatment system for a multi-cylinder, reciprocating internal combustion engine having a catalytic converter disposed in an exhaust duct of the engine, comprising a trap disposed in the exhaust duct located upstream of the catalytic converter, said trap is comprised of a metallic or ceramic porous material substantially filling the cross-section of the exhaust duct with randomly oriented passages through said porous material, a pressure difference between an upstream side and a downstream side of said phosphorus trap is less than 1 kilopascal under all engine operating conditions.

[c15] 15. The exhaust aftertreatment system of claim 14, said trap has a volume less than 10% of the swept volume of the cylinders coupled to said trap.

[c16] 16. The exhaust aftertreatment system of claim 14, said porous material has a minimum pore size of about 20 micrometers.

[c17] 17. The exhaust aftertreatment system of claim 14, said porous material has an average pore size of greater than about 80 micrometers.

[c18] 18. The exhaust aftertreatment system of claim 14 wherein a pressure drop across said trap is less than 1 kilopascal.

[c19] 19. The exhaust aftertreatment system of claim 14 wherein the catalytic converter is located within 15 centimeters of said trap.

[c20] 20. An exhaust aftertreatment system for processing exhaust gases from a reciprocating internal combustion engine, comprising a catalytic converter disposed in an exhaust duct of the engine, said catalytic converter has channels for conducting exhaust gases from an upstream end of said catalytic converter to a downstream end of said catalytic converter, said channels are substantially parallel to each other and parallel to a direction of flow through said catalytic converter, said catalytic converter has a ceramic or metallic porous material disposed within said channels from said upstream end of said catalytic converter for a predetermined distance along said catalytic converter, said porous material has randomly oriented passageways, the exhaust gases undergo multiple turns in the course of being transmitted through said porous material.

[c21] 21. The exhaust aftertreatment system of claim 120, said porous material is comprised of a foam with pore size greater than about 20 micrometers and average pore size greater than about 80 micrometers.

[c22] 22. The exhaust aftertreatment system of claim 20, said predetermined distance is less than one-third of a length of said catalytic converter.

[c23] 23. The exhaust aftertreatment system of claim 20, said predetermined distance is based on a cross-sectional area of said catalytic converter and a swept volume of the engine, said swept volume is a total volume through which pistons of the engine reciprocate.

[c24] 24. The exhaust aftertreatment system of claim 23, said predetermined distance is less than 15% of said swept volume divided by said cross-sectional area.

- [c25] 25. An exhaust aftertreatment system for a reciprocating internal combustion engine, comprising:
- a phosphorus trap disposed in an exhaust duct of the engine, said trap is comprised of a porous material substantially filling the cross-section of the exhaust duct, said porous material has an average pore size greater than a predetermined pore size, said porous material has randomly oriented passageways forcing exhaust gases passing through said porous material to undergo multiple turns so that phosphorous containing materials are trapped in said phosphorous trap;
- a catalytic converter disposed in said exhaust duct of the engine located downstream of said phosphorus trap; and
- an electronic control unit operably connected to the engine, said electronic control unit provides an indication of an amount of said trapped phosphorous and raises temperature in said phosphorous trap above a predetermined temperature when said amount of phosphorous containing material exceeds a predetermined quantity.
- [c26] 26. The system of claim 25 wherein said indication is based on a time of engine operation since temperature in said phosphorus trap last exceeded said predetermined temperature.
- [c27] 27. The system of claim 25 wherein said indication is based on engine speed since temperature in said phosphorus trap last exceeded said predetermined temperature.
- [c28] 28. The system of claim 25 wherein said predetermined temperature is greater than 225 degrees Celsius.
- [c29] 29. The system of claim 25 wherein said engine is a spark ignition engine and a spark ignition timing of the engine is retarded to cause said rise in temperature in said phosphorus trap.
- [c30] 30. The system of claim 25 wherein a speed of the engine is increased to cause said rise in temperature in said phosphorus trap.
- [c31] 31. The system of claim 25, said predetermined pore size is greater than about

Species	Year	Sex	Age	Weight (g)	Length (mm)	Wing (mm)	Tail (mm)	Culmen (mm)	Bill (mm)	Foot (mm)	Toe (mm)	Middle toe (mm)	Claw (mm)	Bill (mm)	Foot (mm)	Toe (mm)	Middle toe (mm)	Claw (mm)
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♂	Ad	100	110	55	45	15	15	15	15	15	15	15	15	15	15	15
Red-tailed Tropicbird	1964	♀	Ad	100	110	55	45	15	15	15								